ELSEVIER

Agricultural Economics 18 (1998) 217–231

AGRICULTURAL ECONOMICS

Adjustment costs and dynamic factor demands for U.S. cigarette manufacturing

Anthony N. Rezitis, A. Blake Brown*, William E. Foster

Department of agricultural and Resource Economics, North Carolina State University, Box 8109, Raleigh NC 27695-8109, USA

Received 29 April 1997; received in revised form 30 December 1997; accepted 6 February 1998

Abstract

Following the approach of Berndt, Fuss, and Waverman, a dynamic model for U.S. cigarette manufacturing is developed and factor demands estimated. Tobacco and capital stocks are treated as quasi-fixed inputs. The results indicate that there are significant adjustment costs associated with adjusting tobacco stocks, but not with adjusting the capital stock. Short-run, intermediate-run, and long-run output constant elasticities are estimated for inputs in cigarette production. Demand for U.S. tobacco by U.S. cigarette manufacturers is found be more inelastic than shown by previous studies using static models. Cigarettes produced for export appear to differ in their marginal cost of production from cigarettes produced for the sale in the U.S. market.

Keywords: US cigarette manufacturing; Adjustment costs

1. Introduction

Few commodities find as frequent media attention and as close public scrutiny as tobacco. While much debate centers on aspects of public health and the propriety of government policies regulating and deterring smoking, the effects of such policies at the farm level and their potential influence on the federal tobacco program are of much interest. Evidence of this interest, expressed not only by farm groups, but by anti-smoking advocates as well, is found in the continuing contentious debate surrounding legislation defining production policy (Barnett, 1995). Economists are frequently called upon to provide applied economic analysis as an input into this policy debate. Sumner emphasizes the importance of such applied work to the policy process, and notes that underlying and essential to practical, issue-specific analysis is a separate category of "policy-useful economics" concerning the 'development of information on empirical or conceptual relationships' (Sumner, 1993 p.4).

Since the federal tobacco program sets the quantity of tobacco marketed and attempts to set tobacco price, much of the policy debate revolves around what is the appropriate response to a decline in demand (i.e. should price or quantity be allowed to fall). The primary focus of this study is to contribute to the analytical foundations of this debate by improving available elasticity estimates for the derived demand for tobacco and other inputs to the cigarette manu-

*Corresponding author. Tel.: 001 919 515 4536; fax: 001 919 515 6268; e-mail: blake_brown@ncsu.edu

0169-5150/98/$19.00
PII S0169-5150(98)00038-3

facturing process. This paper falls into the category of developing or improving the economic parameters that are essential to any sort of 'policy-useful' economic analysis concerning the effects of public anti-smoking policies and consequent changes in farm level policy on tobacco producing areas.

Two previous studies estimate elasticities for the derived demand for tobacco and other inputs to the cigarette manufacturing process: Sumner and Alston use a generalized Leontief cost function, and in a more recent work Beghin and Chang take a translog cost approach. The existing studies develop elasticity estimates in a static framework. A relevant question is whether cigarette manufacturing is more accurately modeled using a dynamic specification or adequately represented by static approaches. Multi-period adjustments of quasi-fixed inputs influence factor demand decisions, and consequently explanations of industry behavior using static models may be misleading.

Two observations about the cigarette industry raise the question of the appropriateness of using a dynamic specification. First, cigarette manufacturing requires substantial investments in plants and specialized equipment. Consequently, we investigate whether or not there are significant adjustment costs associated with changing the capital stock. Adjustment costs occur when firms suffer short-run costs of changing quantities of quasi-fixed inputs. Adjustment costs may result from changes in the capital stock because of output losses associated with stopping plant production to install or de-install equipment, the expense of reorganization of production lines, and the expense of learning to use new equipment and procedures.

Second, cigarette manufacturers hold large inventories of tobacco from which to manufacture cigarettes. This study addresses whether or not there are adjustment costs associated with changing tobacco stocks. One reason all manufacturers give for holding large inventories of tobacco across several crop years is that the quality of tobacco may vary considerably from one crop to another. Unlike some other storable agricultural commodities, grain, for example, tobacco quality may vary substantially in flavor characteristics within a given grade across crop years. Large inventories of tobacco are also useful in aging, and in providing flexibility in production decisions (Tennant, 1950, Chap. 9; and Johnson, 1984, Chap. 2). Freshly cured tobacco is lacking in flavor and aroma compared to aged tobacco. Consequently, inadequate stocks may impose costs to the companies because of changes in blending consistency of their products or increasing use of flavorings and other materials for the company to achieve the same blending consistency of the final product as with the use of aged leaves.

Other sources of adjustment costs associated with tobacco stocks may be related to the preparation of storage and storage itself which are important processes in the cigarette manufacturing industry (Tennant, 1950, Chap.9; Johnson, 1984, Chap.2). Temperature and humidity are strictly regulated. Large quantities of tobacco typically are moved from one process to the next in a regulated routine. Quality of the stored tobacco is maintained by repeated inspections. Changes in the stock of tobacco may impose additional costs, which increase with the size of stock changes. Sources of these costs might be associated with moisturizing and temperature adjustments, and other adjustments in storage procedures; and with administrative changes in inventory maintenance and quality inspection, and with coordination of the new mix of available varieties and grades. Our empirical analysis determines whether or not tobacco or capital stock are quasi-fixed inputs.

We define dynamic input demands for cigarette manufacturing in order to determine the effects of changes on relative prices on the substitution of inputs. In modeling the cost function for the cigarette manufacturing industry, the adjustment cost approach of Berndt et al., 1979 is used to test the existence of quasi-fixed inputs and to generate the dynamics of the production process. One important result of the adjustment cost approach presented in this paper is the estimation of short-run, intermediate-run, and long-run demand elasticities of the inputs used in the U.S. cigarette manufacturing industry.

While the primary focus of the paper is to improve the elasticity estimates needed for policy analysis by examining the appropriateness of a dynamic specification, the model specification allows examination of two other important issues. By extending the econometric application to the case of multiple outputs (i.e. more than one cigarette product), the hypothesis of the equality of marginal costs is tested for production of cigarettes for export versus production for the domestic market. This is of interest because of the expanding production of cigarettes for export. Further, the hypothesis of market power in setting prices in both the cigarette export and domestic markets is tested. The adjustment cost approach of Berndt et al., 1979 employed in this paper has proven useful in diverse areas of research, including manufacturing demand for energy (Denny et al., 1981; Berndt et al., 1981; Vlachou and Field, 1987), issues of short-run labor productivity (Morrison and Berndt, 1981), and the determinants of investment and the effects of tax policy in agriculture (Lopez, 1985; Halvorsen, 1991; Leblanc and Hrubovcak, 1986).

The next two sections give the details of the theoretical background and empirical specification for the dynamic model. Empirical results from estimating the model, tests of the adjustment cost hypotheses, short-run, intermediate-run, and long-run elasticities, results of the tests for equality of product marginal costs, and the results for the test for market power are then presented. The final section discusses the policy implications of the results and conclusions.

2. Theoretical considerations

In general a multi-product firm produces k different outputs $Qt = (Q_{t1}, Q_{t2}, \cdots Q_{tk})$, receiving prices $P_t = (P_{t1}, P_{t2}, \cdots P_{tk})$, by using m variable inputs $V_t = (V_{t1}, V_{t2}, \cdots V_{tm})$ at prices $W_t = (W_{t1}, W_{t2}, \cdots W_{tm})$ and the services of n number of stocks of quasi-fixed inputs $K_t = (K_{t1}, K_{t2}, \cdots K_{tn})$ which can be purchased at asset prices $q_t = (q_{t1}, q_{t2}, \cdots q_{tn})$ and subject to depreciation rates of $Z = (z_1, z_2, \cdots z_n)$. Although there is some disagreement as to the importance of various possible sources of adjustment costs, the literature agrees that adjustment costs arising within a firm lead to optimal multi-period modifications of the levels of quasi-fixed inputs in response to single-period price changes; and that a firm suffers short-run costs as stocks of quasi-fixed factors change (Eisner and Strotz, 1963; Brechling, 1975; Rothschild, 1971; Schramm, 1970; Gould, 1968; Lucas, 1967a, b).

To motivate the multiproduct cost function approach to estimation it is necessary to modify the typical single-output exposition found in the literature of the underlying primal technology subject to internal costs of adjustment. In any period, t, the technology of a firm subject to such internal adjustment costs may be described by the implicit function $F(Q_t, V_t, \dot{K}_{,t}, t) = 0$, where internal adjustment costs due to the changes in quasi-fixed inputs are introduced through $\dot{K}$, a vector of changes (investments or disinvestment) in quasi-fixed inputs. As the rate of change of each quasi-fixed input increases in a given period, the amount of foregone output rises, and in the single-product case this is measured in terms of decreases in physical units of the product. In the multi-output case, adjustment costs can be summarized in terms of increasing changes in the absolute value of $\dot{K}_{jt}$, ceteris paribus, yielding greater and greater productivity decreases. During any period, additional increases in the quantity of a fixed factor are available at increasing opportunity cost measured by the decline of total product along the expansion path in output space (marginal rates of product transformation equal their respective price ratios)[1] : $\sum_i P_{it} dQ_{it}/d\dot{K}j < 0$ if $\dot{K}j > 0$, and $\sum_i P_{it} dQ_{it}/d\dot{K}j > 0$, if $\dot{K}_j < 0$.

In addition to general dynamic considerations arising from the technology, we also wish to incorporate specific industry characteristics deemed of importance in the literature germane to cigarette manufacture. In order to account for potential pricing power (Sumner, 1993; Sullivan, 1985; Ashenfelter and Sullivan, 1987; Appelbaum, 1982; Porter, 1986), the influence of health information and government smoking restrictions (Hamilton, 1972; Ippolito et al., 1979; Porter, 1986; Bishop and Yoo, 1985; Seldon and Boyd, 1991), and advertising (Porter, 1986; Schmalensee, 1972), we represent the inverse demands of the outputs by the column vector $P_t = D_t(Q_t, B_t, AS_t, X_t)$. The vector of variables, B_t, reflects the relevance in the period in

[1] In the case of multiple products one could measure adjustment costs in terms of changes in a bundle of outputs. We can define the bundle of outputs as the profit-maximizing set. The bundle of outputs or 'output' is the weighted sum of individual product levels with relative marginal rates of product transformation (prices) serving as weights. For a given set of inputs, this aggregate output level is merely a standard measure of productivity when dealing with multiple products. Adjustment costs can be explained intuitively in terms of 'output' shifts. More specifically, adjustment costs in output space can be thought of as scaling back the production transformation frontier, along the expansion path, and as a result opportunity cost of additional input is the change of 'output.' It is our intent to imply by the term expansion path the trace of output bundles defined by the equation of marginal rates of product transformation with output price ratios. In this case, regardless of technology, the MRT does not change along the expansion path.

question of health information and smoking restrictions; AS_t represents a measure of advertising stock[2] (with associated user cost U_{AS}); and X_t represents other exogenous variables affecting demand (e.g. income). The variables and data are discussed in more detail in the following sections and in Table 1.

Given these preliminaries, the dynamic economic problem facing the representative firm manufacturing cigarettes is to maximize the present value of the future stream of profits:

$$\Pi = \max_{v_t Q_t AS_t \dot{K}_t} \int_0^\infty e^{-rt}[D(Q_t, B_t, AS_t, X_t)^T Q_t - W_t^T V_t - q_t^T(\dot{K}_t + ZK_t) - U_{AS}(AS_t)]dt \qquad (1)$$

subject to $K(0)=K_0>0$. The elements of the diagonal matrix Z represents the depreciation rates, z_i. This general optimization problem is solved in two steps. First, the variable costs are minimized, given K_t, $\dot{K}_t$ and Q_t. Second, given the resulting variable cost function, the present value of total net receipts is optimized over the quasi-fixed inputs and output levels. The first step gives rise to a conditional variable cost function, $G(W_t, K_t, \dot{K}_t, Q_t, t) = W_t^T V_t$. Shephard's lema can be applied to the restricted cost function to obtain conditional (or short-run) variable input demands:

$$\frac{\partial G(.)}{\partial W_{ti}} = V_{ti}(W_t, K_t, \dot{K}_t, Q_t, t) \; i = 1, 2 \cdots m \qquad (2)$$

In the second step the dynamic optimization problem is solved, given the variable cost function, using the current-value Hamiltonian, H_t (e.g. Kamien and Schwartz, 1981, p. 151).

$$H = D(Q_t)^T Q_t - G(W_t, K_t, \dot{K}_t, Q_t, t) - q_t^T(\dot{K}_t + ZK_t) - U_{AS}(AS_t) + \lambda_t^T \dot{K}_t \qquad (3)$$

where λ_t is the column vector of current value multipliers. The first-order conditions for this optimal control problem are given by the output (4) and advertising (5) decision rules and the Euler equation.[3]

$$\frac{\partial H}{\partial Q_{ti}} = \frac{\partial D(Q_{ti})}{\partial Q_{ti}} Q_{ti} + D(Q_{ti}) - \frac{\partial G(.)}{\partial Q_{ti}} = 0$$
$$\Rightarrow \frac{\partial D(Q_{ti})}{\partial Q_{ti}} Q_{ti} + D(Q_{ti}) = \frac{\partial G(.)}{\partial Q_{ti}} \quad i = 1, 2 \cdots k \qquad (4)$$

$$\frac{\partial D(Q_t^U, B_t, AS_t, X_t)}{\partial (AS_t)} Q_t^U = U_{AS} \qquad (5)$$

The advertising decision rule (5) indicates that the marginal revenue obtained by increasing advertising stock is equal to the user cost of the advertising stock (U_{AS}). As a result advertising stock is treated, in this model, as an endogenous variable rather than as predetermined.

Treadway (1971, 1974) has shown that the demand for investments in quasi-fixed inputs are derived from the Euler equation Eq. (3) and are written as a multivariate linear differential equation system depending on the matrix of estimable parameters, M:

$$\dot{K} = M(K^* - K) \qquad (6)$$

The elements of the adjustment coefficient matrix, M, depend in turn on the discount rate and the derivatives of the conditional cost function; and consequently integrability conditions can be imposed across all variable input and investment demands. Although in the case of more than one quasi-fixed inputs the values for M are extremely complex, Morrison and Berndt show that the problem is analytically and empirically tractable if M is diagonal where its elements are

[2]Advertising influences demand, and as such it should be accounted for in addressing firm behavior. Early attempts to treat advertising as either a quasi-fixed or variable input in the same manner as the other factors more directly associated with the production process were not successful. Such approaches neither improved our ability to explain variations in factor demands and supplies, nor resulted in anything that would be satisfying in terms of economic intuition. One simple reason for this could be that advertising is not a typical factor of production entering the cost function. Another explanation might lie in the size of the econometric task at hand: the size of the model and the limited degrees of freedom could not support the inclusion of a more general and flexible specification for advertising behavior and still maintain overall results that made sense. Regardless, advertising issues are not central to our study, but because advertising is nevertheless an important element of the cigarette industry we think it proper to account for it, certainly in demand, but also in some manner in the optimization problem (Eq. (1)).

[3]The Euler equation describes the optimal paths of the quasi-fixed inputs and is presented as follows:

$$G_{\dot{K}\dot{K}}\ddot{K} + G_{\dot{K}K}\dot{K} = r(G_{\dot{K}} + q) + G_K + Zq$$

where subscripts denote derivatives, the variable $\ddot{K}$ represents the second partial derivative with respect to time, and the variable 3 is the identity matrix.

Table 1
Variables used in the estimation of the models

Variables	Description	Sources
Quantity of domestic tobacco (*D*)	Domestic disappearance plus change in tobacco stocks (in million pounds)	Tobacco Situation and Outlook
Price of domestic tobacco (W_D)	Weighted average price per pound of flue-cured and burley to growers plus purchaser's accessment (in cents/pound)	Tobacco Situation and Outlook
Quantity of imported tobacco (*I*)	Quantity of imported flue-cured and burley (in million pounds)	World Tobacco Situation, Foreign Agricultural Circular
Price of imported tobacco (W_I)	Average import value of imported tobacco (in cents/pound)	World Tobacco Situation, Foreign Agricultural Circular
Labor (*L*)	Number of persons employed in U.S cigarette manufacturing (in thousands)	Annual Survey of Manufactures
Wages (W_L)	Per-person yearly payrolls (thousand $ per person)	Annual Survey of Manufactures
Intermediate materials (*M*)	Cost of other materials form total cost of materials subtracting the value of domestic and imported tobaccos used by U.S manufacturers (mill. of $)	Costs of materials from the Annual Survey of Manufactures
Capital stock (*C*)	Stock of capital in million of dollars	Annual Survey of Manufactures
Acquisition price of capital (q_C)	Price deflator (=gross investments in current/ investments in 1987 $)	Fixed Reproducible Tangible Wealth in the United States
Tobacco stocks (*T*)	Stocks of flue-cured and stocks of burley (in millions of pounds)	Tobacco Situation and Outlook
Advertising stock (*AS*)	Advertising stock (in millions of dollars)	Nicholls (1951), 988 Boensee (1972), Federal Trade Commission
Acquisition price of advertising (q_{AS})	Advertising implicit price deflator is created from Advertising expenditures and CPM	Schmalensee (1972), Advertising Age, Marketing and Media Decision
Cigarette output (Q^U, Q^E)	(Q^U) is total U.S. consumption in billion pieces and (Q^E) is U.S. exports in billion pieces	Tobacco Situation and Outlook
Cigarette prices(P^U, P^E)	(P^U) U.S. wholesale average price including Federal excise tax and (P^E) per unit value of exported U.S cigarettes adjusted by exchange rate and transportation cost	Tobacco Situation and Outlook, Foreign Agricultural Circular
Per-capita U.S personal income (Y^U)	In thousands of U.S. dollars	Tobacco Situation and Outlook and Economic Report of the President
Per-capita production in industrialized countries (Y^W)	Index number (base year 1990)	International Financial Statistics
DA, DB, DE	1953, 1964 and 1979 Health Reports	Porter (1986)
DC, DF	Advertising Ban (*DC*) and Fairness Doctrine (*DF*)	Porter (1986)

positive, and less than unity (for stability).[4] Long-run capital stock, K^*, is derived from the Euler equation evaluated at the steady state. Specifying the algebraic form of the variable cost function completes the estimable model.

[4]Sufficient conditions for diagonal M are that long-run price elasticities between the quasi-fixed inputs are equal to zero, implying that the marginal product of one quasi-fixed input is not affected by changes in the level of any other quasi-fixed input. This also implies separability in the quasi-fixed factors and in the adjustment costs.

3. Model specification

Cigarette manufacturing can be characterized as producing two outputs: cigarettes for U.S. consumption, Q^U with associated prices P^U, and cigarettes for exports to the rest of the world, Q^E with associated prices P^E. We concentrate on the use of four variable inputs: domestic tobacco V_D with associated prices W_D; imported tobacco V_I with prices W_I; labor V_L with price W_L; and intermediate materials V_M with prices W_M. The possibility of two quasi-fixed inputs are allowed: capital stock C with user costs

U_C, and tobacco stocks T with associated user costs U_T,. Incorporating the hypothesis that at steady state total and marginal adjustment costs are zero, the conditional cost function is specified to have a quadratic functional form where total cost and prices are normalized by the price of materials:

$$G = A_o + (A_W A_Q A_k A_t)\begin{pmatrix} W \\ Q \\ K \\ t \end{pmatrix} + (1/2).(WQKt)$$
$$\times \begin{pmatrix} A_{WW} & A_{WQ} & A_{WK} & A_{Wt} \\ A_{QW} & A_{QQ} & A_{QK} & A_{Qt} \\ A_{KW} & A_{KQ} & A_{KK} & A_{Kt} \\ A_{tW} & A_{tQ} & A_{tK} & A_{tt} \end{pmatrix}\begin{pmatrix} W \\ Q \\ K \\ t \end{pmatrix}$$
$$+\frac{1}{2}(\Delta K)^T A_{\dot{K}\dot{K}}(\Delta K)$$

where $A_{ij} = A_{ji}^T$, and A_{WW}, A_{QQ}, and A_{KK} are symmetric. In order for the adjustment matrix, M, to be diagonal the matrices $A_{\dot{K}\dot{K}}$ and A_{kk} must be diagonal. The scaler t, indexes time as a proxy for technical change. Increasing marginal adjustment costs imply that the diagonal elements of $A_{\dot{K}\dot{K}}$ are positive (i.e. $A_{\dot{C}\dot{C}} > 0$ and $A_{\dot{T}\dot{T}} > 0$). In terms of putting the model to an econometric test, capital (tobacco) stock is subject to the adjustment cost hypothesis if the element $A_{\dot{C}\dot{C}}(A_{\dot{T}\dot{T}})$ of the diagonal matrix $A_{\dot{K}\dot{K}}$ is positive and statistically significant. It is important to emphasize that in order to implement the model input prices are taken as given (but market power is tested in the output market), that continuous net changes in the quasi-fixed inputs, $\dot{K}$, can be represented by discrete net change, $\Delta K = K_t - K_{t-1}$, and that production at time t is a function of the quasi-fixed inputs of the previous period.

Shephard's lema applied to the above variable cost function yields a system of three short-run (conditional) variable input demands:

$$V = A_W + A_{WW}W + A_{WQ}Q + A_{WK}K + A_{Wt}t \quad (8)$$

Negative diagonal elements of A_{WW} (i.e. A_{LL}<0, A_{DD}<0, and A_{II}<0) are necessary in obtaining negative own price elasticities. The short-run conditional demand for materials is obtained from the conditional variable cost function $G(.)$ and employing the relationships given by Eq. (8):

$$V_M = G(.) - W^T V \quad (9)$$

Investment demands are given by

$$\dot{K} = M[(-A_{KK})^{-1}(A_K + A_{KW}W + A_{KQ}Q + A_{Kt}t + U - K] \quad (10)$$

where U=[U_C U_T] is a 2×1 column vector representing user cost of quasi-fixed inputs and M is a 2×2 diagonal adjustment matrix with elements m_{CC} and m_{TT} representing capital and tobacco stock multipliers.[5] The long-run demand for quasi-fixed inputs is derived from (Eq. (10)) evaluated at the steady state, $\dot{K} = 0$. Positive diagonal elements of A_{KK} (i.e. A_{CC}>0 and A_{TT} >0) are necessary in obtaining negative slopes for the demand of quasi-fixed inputs.

Turning to the demand equations, for the U.S. market a linear inverse demand is specified in terms of the wholesale price P_t^U (including the excise tax EXT_t levied on the domestically consumed cigarettes) as a function of quantity consumed, Q_t^U, the per capita income, Y_t^U, advertising stock, AS_t, and health and policy dummy variables, D_t.[6] In terms of its parameter specification, the inverse demand for the U.S.

[5]The adjustment multipliers for capital and tobacco stocks are given by

$$m_{kk} = \frac{1}{2}\left[r - \left(r^2 + \frac{4A_{kk}}{A_{\dot{k}\dot{k}}}\right)^{1/2}\right] k = C, T$$

where A_{kk} and $A_{\dot{k}\dot{k}}$ are the diagonal elements of A_{KK} and $A_{\dot{k}\dot{k}}$ matrices. In terms of testing the model, stability requires that $(A_{kk}/A_{\dot{k}\dot{k}}) \leq (1+r)$.

[6]Five dummy variables are included to account for health information and government policies for smoking. The variable *DA* reflects the 1953 American Cancer Society report asserting that smokers had a higher death rate than non-smokers (1 for 1954 to the present, zero otherwise). The variable *DB* reflects the 1964 Surgeon General's report which linked smoking with lung cancer (1 for 1964 to the present, zero otherwise). The variable *DF* (1 for 1967 to 1970, zero otherwise) reflects the period during which the Federal Communication Commission under the so-called Fairness Doctrine required one anti-smoking commercial be aired on television for every four pro-smoking advertisements. The variable *DC* reflects the Cigarette Smoking Act of 1970, which banned the TV and radio advertising as of January 1, 1971 (1 for 1971 to the present, zero otherwise). The variable *DE* represents the 1979 Surgeon General's report, extending the 1964 report (1 for 1979 to the present, zero otherwise).

cigarettes in the domestic market is:

$$P_t^{\rm U} = u_0 - u_1 Q_t^{\rm U} + u_2 Y_t^{\rm U} + u_3 (AS_t)^{1/2} + u_4(DA) + u_5(DB) + u_6(DC) + u_7(DF) + u_8(DE) + u_9 t \quad (11)$$

In like manner, the inverse demand by the rest of the world is given by

$$P_t^{\rm E} = f_0 - f_1 Q_t^{\rm E} + f_2 Y_t^W + f_3 DA + f_4 DB + f_5 DE \quad (12)$$

The variable Y_t^W represents an index of per-capita world production. The health information dummy variables (*DA*, *DB* and *DE*) are included in (16) to capture the possible effects of health information on the foreign demand for U.S cigarettes.

Based on the forgoing demand specifications, output decision rules (4) can also be specified and estimated:

$$P = A_Q + A_{QW} W + A_{QQ} Q + A_{QK} K + A_{Qt} t + c_0 \quad (13)$$

where P is a 2×1 column vector of output prices: $P = [P_t^{\rm U} P_t^{\rm E}]$, and c_0 is a 2×1 column vector. Following Appelbaum (1979) and Bresnahan (1989), the vector $c_0 = [u_{11} Q_t^u + u_{TX}{\rm EXT}_t, f_{11} Q_t^{\rm E}]$ is important for testing market power in the output markets. Without restricting the coefficients in c_0 to be equal to the slopes of the inverse demands, a test for market power in the domestic market would be to test the null hypothesis that $u_{11}=0$ and in the export market to test the null that $f_{11}=0$.[7]

To complete the model's specification, by employing the inverse demand specification of Eq. (11), the advertising decision rule (5) becomes

$$AS = (1/4)(u_3)^2 (Q_t^{\rm U})^2 \frac{1}{(U_{\rm AS})^2} \quad (14)$$

To summarize, an 11-equation simultaneous system is estimated using the system given by Eqs. (8)–(14).

4. Empirical results

The variables and data sources used in the estimation of the model are listed in Table 1. More detailed description of the data and sources used in the construction of the variables employed in this model are presented in the Appendix A. The time period examined is from 1951 until 1992. The producer price index for intermediate materials and components in manufacturing is used as the price of intermediate materials ($W_{\rm M}$). Advertising stock (*AS*), in million of dollars, is derived from advertising expenditures data using a fixed depreciation rate of 0.33 following Schneider et al. (1981) and is converted to real terms using the implicit price deflator for advertising. The implicit advertising price deflator is used as a proxy for the acquisition price of advertising stock ($q_{\rm AS}$) and is created from the published cost-per-thousand index for each media, and the national advertising expenditures for each media. Capital stock data (*K*) in millions of dollars are calculated from real new capital expenditures data, assuming a fixed depreciation rate of 5 percent. The implicit price deflator for investments in the tobacco manufacturing industry is used as a proxy for the acquisition price ($q_{\rm C}$) of the capital stock and is the ratio of gross investments in current and in 1987 dollars. The per unit user cost of tobacco stocks ($U_{\rm T}$) is given by interest cost calculated as the current weighted price of tobaccos scaled by the net interest rate. The user cost of tobacco stocks used to obtain the statistical results presented in this section does not treat explicitly the appreciation of the quality of tobacco stocks because of the lack of quantitative data about the appreciation of the quality of tobacco stocks because of aging. Note, however, that the robustness of theses results were examined by assuming various rates of appreciation of the tobacco stocks (i.e. 5% and 10%). The statistical results do not present any significant sensitivity to the various rates of appreciation used. The per-unit value of exported

[7]Note that we are testing whether there is market power at the industry rather than the firm level. As Bresnahan emphasizes (p. 1030), markup equations such as Eq. (13) need to be interpreted as an average. Bresnahan suggests following Cowling and Waterson and interprets the vector c_0 in Eq. (13) as industry-average conduct. Clearly, if all firms were price takers, then their levels of marginal cost would be equal, and at the aggregate level the industry's price would be equal to the industry's marginal cost of producing one more unit of output. In other words, only if individual firms are non-competitive would the estimated model indicate a wedge between price and marginal costs, and thus evidence of pricing power being exercised. The tests for $u_{11}=0$ and $f_{11}=0$ do not test whether the domestic and foreign demands facing the industry are horizontal but whether the output decision rules (13) are such that equate prices to marginal costs in both markets. See also Appelbaum (1979).

U.S. cigarettes is converted into foreign currency using an exchange rate (SDRs per U.S. dollars) and is scaled by the CIF/FOB factor for industrial countries (*International Financial Statistics*) to take into account transportation cost. Finally, corporate bond rates (Moody's AAA) are used as a proxy for the real interest rate. Other variables were taken directly from the listed sources.

Nonlinear three-stage-least squares (NL3SLS) was used to estimate the parameters of the 11-equation system imposing the integrability restrictions (i.e. $A_{WW} = A^T_{WW}$, $A_{QQ} = A^T_{QQ}$, $A_{KK} = A^T_{KK}$, $A_{WQ} = A^T_{QW}$, $A_{WK} = A^T_{KW}$, $A_{Wt} = A^T_{tW}$, $A_{QK} = A^T_{KQ}$, $A_{Qt} = A^T_{tQ}$, $A_{Kt} = A^T_{tK}$) and correcting for autocorrelation.[8] Despite the number of observations (42 observations), convergence was easily achieved. This is in contrast to the studies of Berndt et al. (1979) and Morrison and Berndt (1981), where convergence was obtained only after setting to zero certain parameters with large standard errors.

Parameter estimates of the model are reported in the Appendix A. The estimates of parameters A_{LL}, A_{DD}, and A_{II} were negative implying that the variable input demands given by (8) are downward sloping; and the estimates of A_{CC} and A_{TT} were positive implying that the demands for the quasi-fixed inputs given by (10) also have negative slopes. In addition the conditional cost function is concave in the prices of the variable inputs.[9]

With respect to the central question of quasi-fixed factors, the hypothesis of no adjustment costs could not be rejected in the case of the capital stock: the parameter A is statistically significant and less than zero ($A_{\dot{C}\dot{C}} = -0.0012; \chi^2_1 = 92.27$ with $P_{\text{value}} \simeq 0$) indicating that variable cost does not increase as the speed of adjusting capital stock increases. The absence of adjustment costs associated with adjusting the capital stock could be related to the way in which cigarette manufacturing adjusts the capital stock. If adjustments are historically made gradually and in small increments then adjustment costs may not be detected.

Tobacco stock, however, appears to be subject to adjustment costs. The coefficient A is positive and apparently different from zero ($A_{\dot{T}\dot{T}} = 0.0156; \chi^2_1 = 596.21$ with $P_{\text{value}} \simeq 0$), indicating that variable cost increases as the speed of adjusting the tobacco stock increases.[10] The values of the tobacco stock multiplier, m_{TT}, implied by the parameter estimates range over the sample period between 0.0675 and 0.0128, with an average of 0.0333, implying stability. The estimated rate of adjustment for tobacco stocks implies that on average about 3.33 percent of the optimal net investment in tobacco stocks will occur in the first year in response to a change in relative price. As discussed in the Section 1, there are several plausible reasons that support this empirical evidence of adjustment costs in the stock of tobacco. Among them are the importance of using aged tobacco in the manufacturing process, maintenance of consistent quality by blending several crops from several years, and the preparation of tobacco for storage and for use in the manufacturing

[8] Corrections were made for autocorrelation by specifying an AR(2) process in the domestic output demand and an AR(1) process for investment demand for capital, the advertising decision rule, the domestic output decision rule, the export demand and the exported output decision rule. A likelihood ratio test was performed to test the above AR restrictions on the residuals of the model. The results of this test show that the AR restrictions hold ($\chi^2_7 = 410.49$ with $P_{\text{value}} \simeq 0$). In addition, to testing the null hypothesis that the residuals of each equation were white noise (given that the AR processes have been specified to each equation), a chi-squared test was performed on the residuals of each equation with degrees of freedom equal to the number of lags specified. These tests show that the residuals of each equation are white noise. The test is the Ljung modification of the Box–Pierce Q statistic (see SAS System for Forecasting Time Series, p. 66) whose approximate distribution is chi-squared statistic under the null hypothesis that the series is white noise. The following chi-squared statistics give the results of the null hypothesis that the residuals of each equation are white noise: labor ($\chi^2_6 = 4.86$ with $P_{\text{value}} = 0.562$), domestic tobacco ($\chi^2_6 = 1.83$ with $P_{\text{value}} = 0.95$), imported tobacco ($\chi^2_6 = 7.03$ with $P_{\text{value}} = 0.318$), materials ($\chi^2_6 = 3.80$ *with* $P_{\text{value}} = 0.703$), investment on capital ($\chi^2_6 = 9.35$ with $P_{\text{value}} = 0.155$), investment on tobacco ($\chi^2_6 = 3.68$ with $P_{\text{value}} = 0.72$), domestic output demand ($\chi^2_6 = 7.27$ with $P_{\text{value}} = 0.297$), advertising stock ($\chi^2_6 = 0.93$ with $P_{\text{value}} = 0.988$), domestic output decision rule ($\chi^2_6 = 10.55$ with $P_{\text{value}} = 0.101$), export demand ($\chi^2_6 = 5.46$ with $P_{\text{value}} = 0.486$), exported output decision rule ($\chi^2_6 = 3.20$ with $P_{\text{value}} = 0.784$).

[9] The Hessian of second partial derivatives of the conditional cost function (7), G(.), with respect to the prices of the variable inputs is negative semi-definite. The principal minor determinants of the Hessian of G(.) alternate in sign.

[10] Note that the conditional cost function (7), G(.), is not convex in the investment of capital and tobacco stocks. In other words G(.) is not positive semi-definite in the investments of the quasi-fixed inputs because of the finding that capital stock is not a quasi-fixed input.

process. Cigarette manufacturers also argue that rapid changes in blend consistency alienate customers since the flavor characteristics of the cigarette are affected. Thus, any changes in blend and consequently flavor, may be done slowly so that the customer adjusts gradually to the change. Our results seem to support this argument.

Given the evidence of adjustment costs which supports the use of a dynamic specification, the calculation of demand elasticities for inputs from this specification provides an important contribution to policy analysis. Estimation of the system results in parameter estimates from which the short-run, intermediate-run, and long-run price elasticities of input substitution can be computed consistently within the Marshallian framework. These elasticities are presented in Table 2. Derivation of these elasticities follows Morrison and Berndt. The short-run elasticities are defined as those in which stocks are held fixed. The intermediate-run are those in which, in addition to the variable inputs, capital is adjusted completely and tobacco stock is adjusted partially. The long-run elasticities are those in which tobacco stock is allowed to adjust completely. Note that these elasticities are calculated holding output constant. With regard to the short-run price elasticities of substitution, the own price elasticities of the variable inputs are negative and all inputs except materials are inelastic. Domestic and imported tobaccos are substitutes. Labor is a complement with both domestic and imported tobaccos and materials to be substitutes for all other inputs.

With regard to the intermediate-run price elasticities of substitution, the own price elasticities of all inputs except materials are inelastic. Domestic and imported tobaccos are substitutes. Labor becomes a substitute for imported tobacco but remains a complement with domestic tobacco while materials remain substitutes for all other inputs. Domestic tobaccos and tobacco stocks are substitutes, while imported tobaccos are complements with tobacco stocks. Capital stock is a complement with imported and domestic tobaccos. Noteworthy are the small short-run and intermediate-run elasticity estimates which indicate the limited substitutability between domestic and imported tobaccos.

With regard to the long-run price elasticities of substitution, domestic and imported tobaccos remain

Table 2
Output-constant elasticities of input substitution

Price	Labor	Domestic tobacco	Imported tobacco	Materials	Capital stock	Tobacco stock
Short-run						
W_L – Labor	−0.47087	−0.000032	−0.000265	0.10043		
W_D – Domestic tobacco	−0.007044	−0.23174	0.075786	9.62215		
W_I – Imported tobacco	−0.012398	0.016255	−0.28718	2.02697		
W_M – Materials	0.49032	0.21552	0.21166	−12.0785		
Intermediate-run						
W_L – Labor	−0.47094	−0.000028	0.000093	0.095917	0.0005151	0.000003
W_D – Domestic tobacco	−0.006303	−0.23694	0.069167	9.5925	−0.011638	0.0045815
W_I – Imported tobacco	0.004365	0.014836	−0.37732	3.1506	−0.12974	−0.000283
W_M – Materials	0.45328	0.16140	0.38147	−15.4133	0.2209	0.051775
U_C – Capital Stock	0.010312	−0.001068	−0.055551	0.68831	−0.080036	
U_T – Tobacco stock	0.00929	0.061803	−0.017852	1.55427		−0.000297
Long-run						
W_L – Labor	−0.47096	−0.000141	0.0001259	0.093085	0.00051515	0.000097
W_D – Domestic tobacco	−0.030846	−0.40021	0.11633	5.48932	−0.011638	0.14184
W_I – Imported tobacco	0.005885	0.024951	−0.38025	3.40499	−0.12974	−0.008788
W_M – Materials	0.17592	−1.68363	0.91441	−61.8135	0.22090	1.60293
U_C – Capital stock	0.010312	−0.001068	−0.055551	0.68831	−0.080036	
U_T – Tobacco stock	0.30968	2.06009	−0.59506	51.8089		−0.009223

inelastic and they are found to be long-run substitutes. In addition, capital and tobacco stocks are also inelastic. Materials have a high own-price elasticity, which may be due to the aggregation of inputs like paper, filter, flavoring and packing materials into one 'intermediate materials' input. As expected, long-run elasticities are more elastic than short-run or intermediate-run elasticities. It is important to note that the own price elasticities of variable inputs are more inelastic than those calculated by either of the previous derived demand studies using static models (988 Bo and Chang, 1992; Sumner and Alston). Most important to farm-level policy analysis is the own price elasticity for domestic tobacco. Beghin and Chang report an own price, output constant, elasticity of close to -1 for U.S. flue-cured tobacco, while Sumner and Alston report a much larger own price, output constant, elasticity for U.S. tobacco of about -2. In contrast, this study indicates that the long-run own price, output constant, elasticity for U.S. tobacco is -0.40. The implication of this finding for policy analysis is that U.S. cigarette manufacturers are much less price-sensitive with regard to purchases of U.S. tobacco than was previously thought.

The results indicate that imported tobacco and tobacco stocks are complements and that both of them are substitutes for domestic tobacco. One possible explanation could be that imported flue-cured and burley tobaccos are used as fillers due to their low nicotine content and tobacco stock is used together with imported oriental as a flavoring agent.[11] As a result in the long run cigarette companies can use tobacco stock together with imported tobacco in the production of cigarettes and substitute away from domestic tobacco. Labor is a long-run complement with domestic tobacco and a substitute for imported tobacco. The finding that imported and domestic tobaccos are substitutes is consistent with the results of Sumner and Alston and Beghin and Chang. Moreover, the small long-run elasticity estimates reveal the limited substitutability between domestic and imported tobaccos, in agreement with Beghin and Chang. This is in contrast to the Sumner and Alston estimate of the cross-price elasticity of demand for imported tobacco with respect to the price of U.S. tobacco of about 2.0. Capital stock is a substitute for the non-tobacco inputs (i.e. labor and materials) but a complement for the domestic and imported tobaccos.

Besides the central issues of quasi-fixed inputs and calculation of short-run, intermediate-run and long-run elasticities, the model also allows the hypothesis of market power in the output market to be tested. A test of market power in the domestic market is a test that the coefficient u_{11} in the domestic output decision rule (13) is not statistically different from zero. A likelihood ratio test shows that the the null hypothesis of price-taking is rejected at the 10 percent level of significance ($u_{=0}0187; \chi_1^2 = 3.09$ with $P_{\text{value}} = 0.078$) indicating that price is greater than marginal cost. Similarly, a likelihood ratio test of market power in the export market shows that the coefficient f_{11} in the export decision rule (13) is statistically significant and greater than zero ($f_{11} = 0.0833; \chi_1^2 = 3.243$ $P_{\text{value}} = 0.071$).

Using a likelihood-ratio test, the hypothesis of equal marginal costs of domestic and export cigarettes can be rejected ($\chi_9^2 = 27.0867$ with $P_{\text{value}} = 0.001$), implying that domestic and export cigarettes are in fact different products. Most cigarette manufacturers admit that the blends used in cigarettes for foreign markets are different from the blends used in cigarettes for the domestic market. Further, some in the tobacco industry argue that the inputs used in cigarettes for export are of lower quality. For example, some argue that a larger proportion of lower priced and quality imported tobacco is used in cigarettes for export. No data are available to substantiate any of these claims. However, the above test of the equality of marginal costs provides some insight.

With respect to the demands for the two products, both respond to price in the manner expected ($u_1 > 0$; $\chi_1^2 = 20.91$ with $P_{\text{value}} \simeq 0$ and $f_1 > 0$; $\chi_1^2 = 17.11$ with $P_{value} \simeq 0$). The effects of health information and government policies on domestic and export demands are negative as expected and statistically significant (at the 10 percent level) as suggested by the likelihood

[11] Imported tobacco falls into two major categories: oriental and flue-cured and burley. In cigarette production there are two major uses for tobacco leaves: filler and flavoring. With the emergence of low-tar and low-nicotine cigarettes (due to health information), imported flue-cured and burley tobaccos became suitable as fillers because of their low nicotine content while imported oriental leaves and tobacco stocks are used as a flavoring agent.

ratio test performed on the coefficients.[12] In addition, the coefficient of advertising stock is positive ($u_3 = 0.0848$; $\chi_1^2 = 3.0668$ with $P_{\text{value}} = 0.0798$) and significantly different from zero (at the 10 percent level).

The output demand elasticities calculated by year are well within the range of other studies (i.e. Sumner and Alston) and range between −0.3689 and −0.1524 for domestically consumed cigarettes (averaging −0.255), and between −3.8281 and −0.2229 (averaging −1.836) for cigarettes for export.

5. Policy implications and conclusions

The most important finding of this study with regard to farm-level policy is that purchases of U.S. tobacco by U.S. cigarette manufacturers are more inelastic than previously thought. Manufacturers apparently try to restrain fluctuations in levels of tobacco stocks to assure consistency of blend quality and desirable aging of the tobacco. Following Sumner and Alston (pp. 259, 264), the total own price elasticity for U.S. tobacco is −1.46 using the long-run output constant own price elasticity for U.S. tobacco found in this study (−0.4) vs. −2.5 using the output constant own price elasticity for U.S. tobacco found in Sumner and Alston (−2). Sumner and Alston's estimate implies that a 25 percent reduction in the U.S. tobacco price would lead to an increase of about 62 percent in sales of U.S. tobacco. In contrast, results from the dynamic specification indicate that a 25 percent reduction in the U.S. tobacco price would lead to an increase of only about 36 percent.

The U.S. tobacco program sets the quantity of tobacco marketed and consequently influences the price received for tobacco. One of the more contentious questions faced by policy makers is whether or not to allow price or quantity (or both) to fall in the event of negative shifts in tobacco demand, such as those caused by cigarette taxes or smoking restrictions (Brown, 1995). Critical to policy analysis dealing with such questions is the total demand elasticity for tobacco. This point is illustrated by taking one scenario for the farm-level effect of increasing cigarette taxes and smoking restrictions from Brown and applying the own price elasticity for U.S. tobacco found in this study to the results. Based on the results of Sumner and Alston and Beghin and Chang, the own-elasticity of substitution for domestic tobacco ranges from −55 to −70. Consequently, Brown (199), p. 949, Table 3) uses a value of −60 to show that a 45 cent per pack increase in cigarette taxes and a 66 percent increase in the restrictiveness of smoking regulations would result in a 3 percent decrease in tobacco prices and a 4 percent decrease in the quantity of U.S. tobacco used domestically if policy makers choose a policy of allowing price to fall. Total farm revenues are forecast to fall by 2 percent (Brown, 1995, p. 949, Table 3).

In contrast, the own-price elasticity of substitution for domestic tobacco based on the long-run, output constant, own price elasticity estimate from this study is about −13. Again, consider a policy of allowing price, instead of quantity, to fall in response to a negative demand shock. Using Brown's model and the smaller own-price elasticity of substitution, a 45 cent per pack increase in cigarette taxes and a 66 percent increase in smoking restrictions would cause price to fall by 5 percent, instead of 3, and domestic use of U.S. tobacco to fall by 8 percent, instead of 4. Total farm revenues would fall by 5 percent, instead of 2 percent. If policy makers follow analyses that use the more inelastic domestic demand elasticity, then they will be less likely to pursue a policy of allowing price to adjust instead of a policy of allowing quantities to adjust.

The cross-price elasticity estimates are of much interest to policy makers and especially to foreign tobacco producers and multi-national firms involved in foreign production and trade. Sumner and Alston estimated the output constant cross-price elasticity of demand for imported tobacco with respect to the price of U.S. tobacco to be about 2.0. In contrast, the long-

[12] More analytically for the domestic demand, the likelihood ratio test performed on the coefficient for the 1953 American Cancer Society report (*DA*), is $\chi_1^2 = 4.3412$ with $P_{\text{value}} = 0.0372$; for the 1964 Surgeon General's report (*DB*), $\chi_1^2 = 3.1336$ with $P_{\text{value}} = 0.0766$; for the 1979 Surgeon General's report (*DE*), $\chi_1^2 = 3.1857$ with $P_{\text{value}} = 0.0742$; for the advertising ban (*DC*), $\chi_1^2 = 3.2579$ with $P_{\text{value}} = 0.0710$; and for the fairness doctrine (*DF*), $\chi_1^2 = 3.4782$ with $P_{\text{value}} = 0.0621$.

For the foreign demand, the likelihood ratio test performed on the coefficient for the 1953 American Cancer Society report (*DA*), is $\chi_1^2 = 3.5202$ with $P_{\text{value}} = 0.0606$; for the 1964 Surgeon General's report (*DB*), is $\chi_1^2 = 3.3268$ with $P_{\text{value}} = 0.0681$; and for the 1979 Surgeon General's report (*DE*), is $\chi_1^2 = 3.3284$ with $P_{\text{value}} = 0.0658$.

run estimate from this study is 0.12. The limited substitution between foreign tobaccos and U.S. tobacco indicated by the long-run demand elasticities estimated in this study imply that foreign tobacco producers and firms that import tobacco into the U.S. would be much less affected by a change in U.S. tobacco program policy to allow the U.S. price to fall.

Cigarette companies often point out the importance of the growth in cigarette exports in maintaining domestic purchases of U.S. tobacco in the face of declining U.S. cigarette consumption. Farm organizations have voiced concern that cigarettes produced for export may not contain as much U.S. tobacco as cigarettes produced for the U.S. market. Some cigarette companies have countered that cigarettes produced for export are essentially the same product as those produced for the domestic market. Partly in response to this concern, legislation was passed in 1993 that set minimum content requirements for the amount of U.S. tobacco contained in U.S. manufactured cigarettes. While this study does not answer the content question, it does provide evidence that cigarettes produced for export are at least different from cigarettes produced for the domestic market in respect to their marginal cost of production.

Finally, anti-smoking groups, consumer groups, and farm organizations may be particularly interested in the evidence that cigarette companies may exercise market power in the pricing of their product. The question of market power in the industry remains unsettled; some studies rejecting the cartel hypothesis and supporting the hypothesis of at least a moderately high level of competition (i.e. Sumner, 1981; Sullivan, 1985; Ashenfelter and Sullivan, 1987), while others, like this study, support the hypothesis of a noncompetitive industry (i.e. Appelbaum, 1982; Porter, 1986).

If economists are to continue to make useful contributions to policy analysis, then they must continue to improve the parameter estimates necessary for applied policy analysis. This study makes significant contributions to the current policy debate surrounding tobacco by giving new and credible parameters. Not only does this analysis demonstrate the importance of examining dynamic specifications for agricultural commodities, but it also yields parameters that allow development of short-run, intermediate-run, and long-run scenarios for policy changes that affect U.S. tobacco production.

6. Data discussion

Employed labor (L), represents the number of persons employed in cigarette manufacturing and tobacco stemming and redrying, and wage (W_L) is the per person yearly payroll in thousand dollars. Labor data are from the *Annual Survey of Manufactures*. Quantity of U.S. tobacco purchased by U.S. manufactures (D) in million pounds is calculated by adding to domestic disappearance data the change of tobacco stocks held. Average market price of tobacco purchased (W_D) is a weighted average price of the prices of the two tobacco varieties (flue-cured and burley). Tobacco quantity and price data were obtained from *Tobacco Situation and Outlook*. Quantity of imported tobacco (I) in million pounds was obtained from *World Tobacco Situation*. Average import value was used as the price of the imported tobacco (W_I), obtained from the same source. Cost of other materials was deflated by producer price index for intermediate materials in manufacturing and used as the quantity of the intermediate materials input (M) used in cigarette production such as paper, filter, packaging materials. The producer price index for intermediate materials and components in manufacturing is used as the price of intermediate materials (W_M) and is obtained from *Economic Report of the President (1994)*. Materials cost data is derived from the *Annual Survey of Manufactures* and advertising expenses obtained from Federal Trade Commission Report to Congress for various years. Costs associated with tobacco use are not included in the cost of materials data. Advertising stock (AS), in million of dollars is derived from advertising expenditures data using a fixed depreciation rate of 0.33 following Schneider et al. (198)) and is converted to real terms using the implicit price deflator for advertising. The implicit advertising price deflator is used as a proxy for the acquisition price of advertising stock (q_{AS}) and is created from the published cost-per-thousand index for each media, obtained from *Marketing and Media Decisions*, and the national advertising expenditures for each media obtained from *Advertising Age*. Capital stock data (C) in millions of dollars is calculated from real new capital expenditures data, assuming a fixed depreciation rate of 5 percent, which generates measures of capital stock close to those given by book values published by the *Annual Survey of Manufac-*

tures. The new capital expenditures' variable was obtained from the *Annual Survey of Manufactures*. The implicit price deflator for investments in the tobacco manufacturing industry is used as a proxy for the acquisition price (q_C) of the capital stock and is the ratio of gross investments in current and in 1987 dollars obtained from the *Fixed Reproducible Tangible Wealth in the United States, 1925–89* published by the U.S. Department of Commerce. In obtaining the user cost of capital (U_C) the acquisition price of capital (q_C) is scaled by real interest rate and depreciation rate. Tobacco stock (T) data were obtained from *Tobacco Situation and Outlook*. The per unit opportunity cost of tobacco stocks (U_T) is given by interest cost calculated as the current weighted price of tobaccos scaled by the net interest rate. Investment on capital ($\dot{C}$) and investment on tobacco ($\dot{T}$) data were generated for each year by subtracting the past year's value from the current year. Total cigarette output produced by U.S manufactures (in billion pieces), U.S. exports (in billion pieces), U.S. wholesale average price (net price per 1000 pieces including Federal excise tax and net price per 1000 pieces excluding excise tax), U.S personal income (in billion of dollars) and U.S population (in millions), are obtained from *Tobacco Situation and Outlook*. Per-unit price of exported U.S cigarettes is obtained from the value of exports (*World Tobacco Situation and Outlook*) divided by the number of exported U.S cigarettes. The per-unit value of exported U.S. cigarettes is converted into foreign currency using an exchange rate (SDRs per U.S. dollars obtained from various issues of *International Financial Statistics*). The CIF/FOB factor for industrial countries (obtained from various issues of *International Financial Statistics*) takes account of transportation cost by scaling the per-unit values of exported cigarettes. An index number of total production by industrial countries is used as a proxy for world production and this index as well as world population are obtained from the *International Financial Statistics*. Finally, corporate bond rates (Moody's AAA) are used as a proxy for the real interest rate and are obtained from the *Economic Report of the President*.

Appendix A

Table 3

Table 3
Parameter estimates of the dynamic model

Parameter	T-ratio	T-ratio	PROB > $\lvert T \rvert$
A_0	−1462667	−0.06	0.9524
A_L	−1817.19	−0.90	0.3740
A_D	96735.66	3.36	0.0018
A_I	859.45	0.10	0.9190
A_C	28.216	0.26	0.8003
A_T	−117.872	−1.20	0.2382
$A_{L\ L}$	−115.426	−0.99	0.3287
$A_{D\ D}$	−145.988	−0.93	0.3613
$A_{I\ I}$	−44.589	−1.42	0.1666
A_{CC}	0.000268	0.70	0.4899
$A_{T\ T}$	0.00277	1.89	0.0674
$A_{C\ T}$	na	na	na
A_{QU}	−398.955	−0.25	0.8009
A_{QE}	−1597.12	−0.85	0.4042
$A_{QU\ QE}$	0.0839	1.33	0.1939
$A_{QE\ QE}$	−0.174	−1.29	0.2053
$A_{QU\ QU}$	−0.0626	−0.95	0.3504
$A_{L\ D}$	−0.1874	−0.01	0.9903
$A_{L\ I}$	−0.3537	−0.05	0.9640
$A_{L\ QE}$	−0.0716	−1.22	0.2315
$A_{L\ QU}$	−0.0056	−0.10	0.9175
$A_{L\ C}$	−0.00208	−0.40	0.6950
$A_{L\ T}$	−0.0034	−0.48	0.6321
$A_{D\ I}$	10.977	0.20	0.8405
$A_{D\ QU}$	3.5018	3.75	0.0006
$A_{D\ QE}$	−0.2768	−0.28	0.7777
$A_{D\ C}$	0.0051	0.08	0.9346
$A_{D\ T}$	−0.5421	−5.61	0.0001
$A_{I\ QE}$	−0.7448	−2.69	0.0108
$A_{I\ C}$	0.0612	3.32	0.0020
$A_{I\ QU}$	0.4685	1.80	0.0800
$A_{I\ T}$	0.036	1.27	0.2128
$A_{QE\ C}$	−0.0071	−1.72	0.0942
$A_{QU\ C}$	−0.00054	−0.20	0.8434
$A_{QU\ T}$	0.00501	1.06	0.2960
A	−0.00124	−0.92	0.3629
A	0.01526	6.13	0.0001
A	na	na	na
$A_{QE\ T}$	−0.01117	−1.18	0.2477
u_0	−40.3791	−3.06	0.0046
u_1	0.0020	2.77	0.0088
u_2	−0.4285	−0.25	0.8021
u_3	0.0848	1.67	0.1031
u_4	−0.0513	−1.32	0.1972
u_5	−0.0153	−0.34	0.7353
u_6	−0.0299	−0.52	0.6055
u_7	−0.0336	−0.71	0.4808
u_8	−0.0164	−0.42	0.6805
u_9	0.0213	3.08	0.0043
u_{11}	0.0187	0.40	0.6908
u_{TX}	−126.043	−0.96	0.3419
f_0	0.18146	3.52	0.0012
f_1	0.0025	3.73	0.0007

Table 3 (continued)

Parameter	T-ratio	T-ratio	PROB > $\|T\|$
f_2	−0.0041	−0.04	0.9694
f_3	0.01409	0.75	0.4596
f_4	−0.01110	−0.48	0.6330
f_5	−0.0127	−0.60	0.5528
f_{11}	0.0833	0.88	0.3843
A_t	1756.11	0.07	0.9449
$A_{t\ t}$	−0.5125	−0.08	0.9379
$A_{L\ t}$	0.9688	0.92	0.3614
$A_{D\ t}$	−48.758	−3.26	0.0024
$A_{QE\ t}$	0.8173	0.84	0.4077
$A_{QU\ t}$	0.2117	0.26	0.7963
$A_{C\ t}$	−0.0147	−0.26	0.7979
$A_{T\ t}$	0.0549	1.10	0.2797
$A_{I\ t}$	−0.5327	−0.12	0.9034
DKS_L1	0.8591	12.82	0.0001
QU_L1	0.5057	2.49	0.0185
QU_L2	0.3526	1.70	0.0998
ASQ_L1	1.0134	6.44	0.0001
NPCIGT_1	1.0738	7.46	0.0001
QE_L1	1.1116	32.47	0.0001
PEXCIG_1	0.98453	7.78	0.0001

References

Appelbaum, E., 1979. Testing price taking behavior. Journal of Econometrics 9, 283–294.

Appelbaum, E., 1982. The estimation of the degree of oligopoly power. Journal of Econometrics 19, 287–299.

Ashenfelter, O., Sullivan, D., 1987. Nonparametric test of market structure: An application to the cigarette industry. Journal of Industrial Economics 35, 483–498.

Barnett, T.O., 1995. Report of the advisory committee on the government flue-cured land burley tobacco program. Covington and Burling, Attorneys, Washington DC, April 27 1995.

Beghin, J.C., Chang, R.E., 1992. Differentiated products and supply controls in the analysis of agricultural policy reform: The case of tobacco. Agricultural Economics 7, 301–315.

Berndt, E.R., Fuss, M.A., Waverman, L., 1979. A dynamic model of cost of adjustment and interrelated factor demands, with an empirical application to energy demand in U.S. manufacturing. Working Paper 7925. Institute for Policy Analysis, University of Toronto, Canada.

Berndt, E.R., Morrison, C.J., Watkins, G.C., 1981. Dynamic models of energy demand: An assessment and comparison. In: Berndt, E.R., Fields, B.C. (Eds.), Modeling and Measuring Natural Resource Substitution. MIT Press, Cambridge, MA, pp. 259–289.

Bishop, J.A., Yoo, J.H., 1985. Health scare, excise taxes and advertising ban in the cigarette demand and supply. Southern Economic Journal 52, 402–411.

Brechling, F., 1975. Investment and Employment Decisions. Manchester University Press, Manchester, UK.

Bresnahan, T.F., Empirical studies of industries with market power. In: Schmalensee, R., Willig, R.D. (Eds.), Handbook of Industrial Organization, vol. II, Elsevier, 1989, pp. 1011–57.

Brown, A.B., 1995. Cigarette taxes and smoking restrictions: Impacts and policy implications. American Journal of Agricultural Economics 77, 946–951.

Cowling, K., Waterson, M., Price cost margins and market structure. Economica 43, 267–74.

Denny, M., Fuss, M.A., Waverman, L., 1981. Substitution possibilities for energy: Evidence from U.S. and Canadian manufacturing industries. In: Berndt, E.R., Fields, B.C. (Eds.), Modeling and Measuring Natural Resource Substitution. MIT Press, Cambridge, MA, pp. 230–258.

Eisner, R., Strotz, R.H., 1963. Determinants of business investment. In: Impacts of Monetary Policy, Research Study II, prepared for the Commission on Money and Credit. Prentice-Hall, Englewood Cliffs, NJ.

Federal Trade Commission, Report to Congress: Pursuant to the Federal Cigarette Labeling and Advertising Act, mimeos (various years).

Gould, J.P., 1968. Adjustment costs in the theory of investment of the firm. Review of Economic Studies 35, 47–55.

Halvorsen, R., 1991. The effects of tax policy on investment in agriculture. Review of Economics and Statistics 73, 393–400.

Hamilton, J.L., 1972. The demand for cigarettes: Advertising, the health scare and the cigarette advertising ban. Review of Economics and Statistics 54, 401–411.

Ippolito, R.A., Murphy, R.D., Sant, D., 1979. Consumer Responses to Cigarette Health Information, Federal Trade Commission Staff Report, Washington DC, August 1979.

Johnson, P.R., 1984. The Economics of the Tobacco Industry. Praeger, New York.

Kamien, M.I., Schwartz, N.L., 1981. Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management. North-Holland, New York.

Leblanc, M., Hrubovcak, J., 1986. Dynamic input demand: An application to agriculture. Applied Economics 18, 807–818.

Lopez, R.E., 1985. Supply response and investment in the Canadian food processing industry. American Journal of Agricultural Economics 62, 40–48.

Lucas, R.E., 1967a. Optimal investment policy and the flexible accelerator. International Economic Review 8, 78–85.

Lucas, R.E., 1967b. Adjustment costs and the theory of supply. Journal of Political Economy 75, 321–334.

Morrison, C.J., Berndt, E.R., 1981. Short-run labor productivity in a dynamic model. Journal of Econometrics 16, 339–365.

Porter, R.H., 1986. The impact of government policy on the U.S. cigarette industry. In: Ippolito, P.M., Scheffman, D.T. (Eds.), Empirical Approaches to Consumer Protection Economics, Federal Trade Commission, Washington DC, March, 1986, pp. 447–481.

Rothschild, M., 1971. On the cost of adjustment. Quarterly Journal of Economics 85, 605–622.

Schmalensee, R., 1972. The Economics of Advertising, North-Holland, Amsterdam.

Schneider, L., Klein, B., Murphy, K.M., 1981. Government regulation of cigarette health information. Journal of Law and Economics 24, 575–612.

Schramm, R., 1970. The influence of relative prices, production conditions and adjustment costs on investment behavior.. Review of Economic Studies 37, 361–376.

Seldon, B.J., Boyd, R., 1991. The stability of cigarette demand. Applied Economics 23, 319–326.

Sumner, D.A., 1981. Measurement of monopoly behavior: An application to the cigarette industry. Journal of Political Economy 89(5), 1010–1019.

Sumner, D.A., 1993. Economic analysis for better agricultural trade policy. The 1993 James N. Snyder Memorial Lecture, Purdue University, Purdue, IN.

Sumner, D.A., Alston, J.M., Substitutability for farm commodities: The demand for tobacco in cigarette manufacturing. American Journal of Agricultural Economics, 69(2), 258–265.

Sullivan, D., 1985. Testing hypothesis about firm behavior in the cigarette industry. Journal of Political Economy 93, 586–599.

Tennant, R.B., 1950. The American Cigarette Industry. Yale University Press, New Haven, CT.

Treadway, A.B., 1971. On the rational multivariate flexible accelerator. Econometrica 39, 845–856.

Treadway, A.B., 1974. The globally optimal flexible accelerator. J. Economic Theory 7, 7–39.

U.S. Department of Commerce, Bureau of Census, Annual Survey of Manufacturers, various years.

Vlachou, A., Field, B.C., 1987. Regional energy substitution: Results from a dynamic input demand model. Southern Economic Journal 53, 955–966.